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EFFECTS OF FOREPERIOD, INDUCED MUSCULAR TENSION, AND STIMULUS REGULARITY ON SIMPLE REACTION TIME¹

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Davis (3) has shown that the tension of the responding muscle system, as measured with surface electromyograms, increases during the foreperiod of reaction and reaches a maximum at the end of the foreperiod. He has also shown that the greater the tension level reached, the shorter the reaction time (RT). It might be deduced from this that the longer the foreperiod, the greater the tension that can be developed, and therefore, that there is an inverse relationship between length of foreperiod and RT. However, under the conditions of Davis' study this is not true, as Davis has shown, at least when foreperiods vary irregularly in length during the reaction series. Under these conditions, Davis found that maximum tension and shortest RT's were obtained with that foreperiod whose length was about average for the irregular series.

Other information concerning the relations among foreperiod, tension, and reaction time comes from studies of induced muscular tension. These studies (1, 5, 6, 7, 8) also report an inverse relationship between tension level and RT. However, in studies done by Freeman (6) and Freeman and Kendall (7) with irregularly presented foreperiods and induced tension levels, it was found that the foreperiod which was most effective in producing a short RT was longer with the greater than it was with the

lesser of the two induced tensions used. Thus, there appears to be some support for the hypothesis that RT is inversely related to foreperiod length and that this relationship depends on the inverse relationship between tension level and RT.

On the other hand, this result appears in direct contradiction to that obtained by Davis. Since in Davis' experiment only the foreperiod was variable, whereas in Freeman's studies both foreperiod and tension magnitude were variable, it is possible that differences in stimulus regularity between the experiments may account for the difference in results. The present investigation was designed to study this problem and, in addition, to provide further information on the relationships among RT, foreperiod, and magnitude of induced tension.

The apparatus is shown in Fig. 1.² Muscular tension (load) was induced by having S pull against a calibrated spring during the entire foreperiod. Force of pull was monitored for S by a red, jewelled light which flashed on and off if his pulling force fluctuated. This light also initiated the foreperiod. The S held his arm in the same chinning position under all load conditions. The RT was for the initiation of a slight extra pull or jerk against the spring in response to the onset of a second, green, jewelled light the duration of which was 2 sec. Foreperiods and stimulus durations were controlled with Hunter timers. The RT was measured as the initial displacement of a pendulum in response to S's reaction movement. This was recorded to an accuracy of .0001 sec. with a Hewlett-Packard counter. Intertrial interval

¹The major results of this study were presented at the 1956 meeting of the Eastern Psychological Association.

²The apparatus was designed and constructed by Dr. John L. Kobrick and is described elsewhere (9).

was monitored manually with the aid of a Standard Electric timer measuring in .01 sec.

EXPERIMENT I

Design

Experiment I used 75 soldiers as Ss. A randomized block design was employed in which each subgroup (cell) performed under one regularly presented combination of load and foreperiod and with either a 10- or 30-sec. intertrial interval. The Ss were given 24 trials per day for two successive days. Foreperiods of 2, 6, and 10 sec. were combined with loads of 5, 20, and 35 lb. except that no 35-lb. loads were used with massed practice. Although the total *N* of the experiment is fairly large, the experimental design allowed only five Ss per cell, and thus the reliability of the cells is somewhat lower than might be desired. Actually, Exp. I was designed as a preliminary experiment intended to give Ss practice and aid in the selection of foreperiod and load values for the remaining experiments. However, the results are suggestive and appear to warrant presentation in spite of their largely preliminary nature.

Results

All RT's were transformed to reciprocals in both this and subsequent experiments in order to reduce the skew commonly associated with latency measures. The reciprocal of a latency, by its very nature, provides an index of speed and shall be referred to as such. The mean reciprocals for

the various conditions of the experiment are presented in Table 1. The values shown are based upon summations over all 48 trials of both experimental days since statistical analysis showed no effect due to either trials or days. Each value in this table, therefore, is based upon 240 observations.

The results shown in Table 1 with the more distributed practice condition are very difficult to interpret. The most serious problem, from the point of view of the present study, is the failure of these results to show a consistent increase in speed with increased tension. On the other hand, it may be seen that a consistent effect was obtained with the 10-sec. intertrial interval. In addition, it may be seen that the 6-sec. foreperiod was optimum with the massed trials, but no consistent optimum appeared with the distributed trials. In the latter case, the 2-sec. foreperiod was most frequently optimum.

Table 2 presents a summary of an analysis of variance of the data upon which Table 1 is based. To perform this analysis the 35-lb. row of the 30-sec. intertrial interval condition was omitted. Separate analyses of the two parts of Table 1 did not provide any different information. Inspection of Table 2 indicates that foreperiod and load were significant main effects. The simple interactions of each of these with intertrial interval was also significant as was the corresponding second-order interaction. No other effect had significance within the usual probability criteria. Thus, it would appear that differences in speed of reaction were produced by both the foreperiods and the loads used, but that these differences were not homogeneous for the two intertrial intervals. In view of these results and the fact that the 10-sec.

TABLE 1
MEAN RECIPROCAL RT FOR CONSTANTLY
PRESENTED LOAD AND FOREPERIOD

Load (Lb.)	Foreperiod (Sec.)		
	2	6	10
30-Sec. Intertrial Interval			
5	3.28	3.10	3.06
20	3.27	2.96	3.42
35	4.09	3.17	3.30
10-Sec. Intertrial Interval			
5	3.19	3.11	2.70
20	3.20	3.99	3.02

TABLE 2
ANALYSIS OF VARIANCE, EXP. I

Source	df	MS	F
Days (D)	1	4.24	—
Trials (T)	23	4.89	1.12
Loads (L)	1	39.02	8.95*
Foreperiods (F)	2	14.71	3.37**
Intertrial interval (I)	1	.10	—
D × T	23	2.34	—
D × L	1	5.13	1.18
D × F	2	6.98	1.60
D × I	1	.16	—
T × L	23	4.71	1.08
T × F	46	3.85	—
T × I	23	5.78	1.32
L × F	2	9.80	2.25
L × I	1	18.80	4.31**
F × I	2	47.79	10.96*
D × T × L	23	3.61	—
D × T × F	46	4.04	—
D × T × I	23	2.71	—
D × L × F	2	6.02	1.38
D × L × I	1	4.73	1.08
D × F × I	2	6.55	1.50
T × L × F	46	3.10	—
T × L × I	23	5.73	1.31
T × F × I	46	3.68	—
L × F × I	2	19.61	4.50**
Error	2467	4.36	n.s.***
Total	2879		

* $P < .01$.** $P < .05$.

*** None of the pooled interactions was significant.

intertrial interval appeared to be more sensitive to the effects of induced tension, the 10-sec. interval was used in the following three experiments. The same range of loads and approximately the same range of foreperiods were used since these had been shown to be effective here.

EXPERIMENT II

Design

Experiment II was a split plot in which foreperiods of 2, 5, 8, and 11 sec. were presented 10 times each in random order making a total of 40 consecutive reactions elicited from each S. Forty-eight Ss of the previous experiment were assigned at random to subgroups of 12 Ss, each of which performed with a constant load of 5, 15, 25, or 35 lb. and the irregular foreperiods noted.

Results

Analysis of variance (Table 3) indicated that, of the within-S effects, both the differences between foreperiods and between trials were significant. The foreperiods-trials interaction was also significant. The effects of load were not significant; but since this was the confounded part of the split plot, no conclusion is warranted (2).

Inspection of the reciprocals on a trial-by-trial basis showed that the significance attributable to trials was due to a warm-up phenomenon which was generally overcome by the second trial. The foreperiod-trials interaction was due to the difference in the magnitude of this warm-up effect. Otherwise no trend toward either increased or decreased reaction speeds was apparent among any of the foreperiod conditions. The curves obtained were essentially parallel lines. For this reason the reciprocals were summed over trials and means obtained in order to determine the general effects of the foreperiods under

TABLE 3
ANALYSIS OF VARIANCE, EXP. II

Source	df	Mean Square	F
Between Ss	47	7.20	
Loads (L)	3	1.39	
Error (b)	44	7.60	
Within-Ss	1872	.30	
1. Foreperiods (F)	3	6.74	13.22*
2. Trials (T)	9	2.57	8.56*
3. F × T	27	1.04	4.38*
4. F × L	9	.20	
5. T × L	27	.19	
6. F × T × L	81	.20	
Error Within-Ss	1716	.27	
Error—1, 4	132	.50	
Error—2, 5	396	.30	
Error—3, 6	1188	.24	
Total	1919		

* $P < .01$.

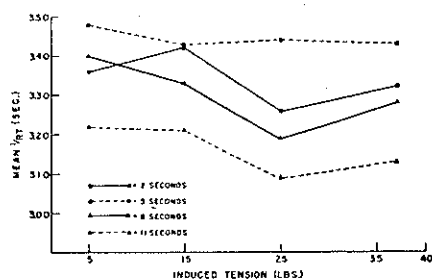


FIG. 1. Speed of reaction with different foreperiods as a function of induced tension when foreperiods were irregularly presented and loads were regularly presented during the reaction series.

the conditions of this experiment. The result of this procedure is shown in Fig. 1. Each point on this graph is based upon 120 observations. Inspection of this figure shows that the 5-sec. foreperiod was the most effective at all load conditions. This figure also suggests that the greatest speeds were achieved with the lighter loads and, in addition, suggests a possible worst load at the 25-lb. level. However, as noted above, the significance of these effects cannot be determined.

EXPERIMENT III

Design

Experiment III was also a split-plot design. The same 48 Ss used in the previous experiment were randomly assigned to new subgroups of 12, each of which responded with a constant foreperiod of 2, 5, 8, or 11 sec. All Ss were presented loads of 5, 15, 25, or 35 lb. ten times each in one 40-trial random series.

Results

Analysis of variance (Table 4) indicated that the main effects of the loads and of trials were the only significant effects. As in the previous experiment, the significance of trials could be accounted for by a quickly overcome warm-up effect. Other than this effect no trend toward either increasing or decreasing reaction

TABLE 4
ANALYSIS OF VARIANCE, EXP. III

Source	df	Mean Square	F
Between-Ss	47	13.10	
Foreperiods (F)	3	30.21	2.54
Error	44	11.93	
Within-Ss	1872	.32	
1. Loads (L)	3	4.62	7.57*
2. Trials (T)	9	.96	3.43*
3. L \times T	27	.19	—
4. L \times F	9	.22	—
5. T \times F	27	.34	1.21
6. T \times F \times L	81	.26	—
Error Within-Ss	1716	.32	
Error—1, 4	132	.61	
Error—2, 5	396	.28	
Error—3, 6	1188	.29	

* $P < .01$.

speeds was discernible in the trial series. Inspection of Table 4 shows that the main effect of the foreperiods was short of a significant probability criterion. No conclusion may be drawn from this result by itself. However, Exp. II and III may be thought of as "complimentary" replicates and regarded in this fashion, both foreperiods and loads may be recognized as generally significant factors. This problem, i.e., the loss of power of the between-Ss error term in split-plot designs and the use of "complimentary" replicates, is discussed by Cochran and Cox (2).

The major results are shown in Fig. 2 which presents mean reciprocal versus load for the different foreperiods. Each value in this graph is based upon 120 measurements. This figure shows that the 5-sec. foreperiod was optimum. It also suggests an increase in response speed with increasing load.

EXPERIMENT IV

Design

In Exp. IV, 15 of the Ss used in the previous experiment were selected at random and pre-

TABLE 5
ANALYSIS OF VARIANCE, EXP. IV

Source	df	Mean Square	F
Ss	14	18.72	
Series (S)	5	2.76	4.25*
Foreperiods (F)	3	12.98	25.96*
Loads (L)	3	.32	
S × Ss	70	.65	
Ss × F	42	.50	
Ss × L	42	.42	
S × F	15	.42	1.11
S × L	15	.34	1.06
F × L	9	.37	1.03
S × Ss × F	210	.38	
S × Ss × L	210	.32	
Ss × F × L	126	.36	
S × F × L	45	.34	1.13
Ss × S × F × L	630	.30	
Total	1439		

* $P < .01$.

sented all 16 combinations of the four loads and four preparatory intervals in one complete randomly arranged series. At the end of this series without pause, a new random series was presented, and so on until six such series were completed.

Results

Analysis of variance of the reciprocals (Table 5) indicated that the main effects of foreperiod length and of

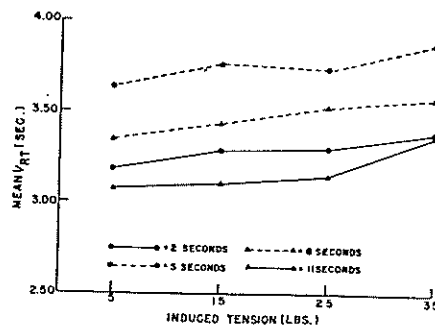


FIG. 2. Speed of reaction with different foreperiods as a function of induced tension when foreperiods were regularly presented and loads were irregularly presented during the reaction series.

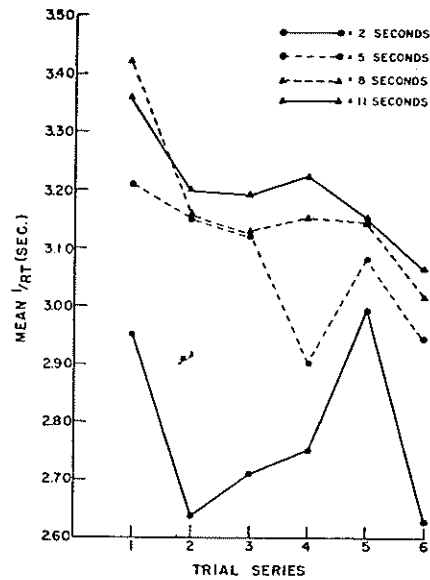


FIG. 3. Speed of reaction with different foreperiods as a function of reaction series when both foreperiod and load were variable.

series were both significant when evaluated over their respective interactions with Ss. Magnitude of load was not a significant main effect. None of the interactions was significant.

The results are shown in Fig. 3 which presents the mean reciprocal versus series for each of the foreperiods. Although the behavior of the curve representing the 2-sec. foreperiod suggests a significant foreperiod series interaction as compared with the other curves, it was not significant according to the statistical analysis. In general, the effects of foreperiod are differentiated throughout the several series. Unlike the previous experiments, it appears that response speed increased the longer the foreperiod. No optimum appears. There is also a suggestion that, except for the 2-sec. interval, there was a decline in response speed from series to series.

CROSS-EXPERIMENT COMPARISONS

The major results of Exp. II, III, and IV are summarized in Fig. 4. This figure allows a cross-experiment comparison of the mean reciprocals for foreperiod and for load summed over all other conditions. It, therefore, allows a comparison of the effects of stimulus regularity on response speed as well as the general effects of load and foreperiod under different conditions of stimulus regularity. Inspection of this figure shows that, except for Exp. IV which involved the greatest degree of stimulus irregularity, the 5-sec. foreperiod was clearly optimum. It is interesting to note that the 5-sec. foreperiod was more marked as an optimum when the foreperiod was constant than when it was irregular. The lack of an optimum shown in the foreperiod curve for Exp. IV is in accord with previous studies (10). However, this result extends them in suggesting the increasing relationship shown.

The results for the effects of induced tension are fairly clear. The curve obtained from Exp. III is based on the statistically most precise premises since this was a within-*S* comparison. This curve suggests that response speed increased systematically with increasing load even when the loads were presented irregularly. The results of Exp. II, which suggest a decrease in speed with

load, are contradictory, but these results are based on the confounded part of the split plot. Even the curve for the irregularly presented load in Exp. IV, which was not significant, shows a slight suggestion of a rise with increasing load. The preliminary results of Exp. I were also quite clear in showing this effect with the same intertrial interval.

The probability of the stimulus condition presented to *S* is given by the product of the separate load and foreperiod probabilities. The stimulus probability of Exp. II and III was .25, and it may be seen that their general response speed level was higher than that of Exp. IV for which the stimulus probability was .06, approximately. Thus, the results indicate that stimulus irregularity is an important factor in speed of reaction.

DISCUSSION

The results are clear in indicating that RT is inversely related to magnitude of tension. This is in agreement both with Davis' (3) study and other studies of induced tension (1, 5, 6, 7, 8). The results agree with Davis (3), but not with Freeman (6), in finding that the foreperiod length associated with the greatest speed of reaction did not change with greater tension levels. The study indicates instead that, at least with highly massed practice, there is an optimum foreperiod length which is independent of tension level in its effect on RT. In fact, since the same optimum was found in Exp. I, II and III, it would not appear that *Ss* responded to the average foreperiod length, as Davis (3) supposed, but rather that there really is an optimum even when the foreperiod length varies randomly.

The results are also clear in showing the effects of foreperiod and tension regularity. When only one of these is irregular and its probability is at least .25, a definite foreperiod optimum appears. For the same probability, the results suggest that speed of reaction is greater when the tension level is irregular than when it is the foreperiod which is

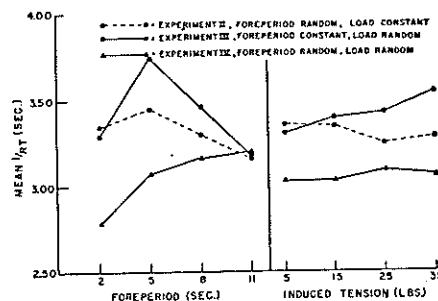


FIG. 4. Speed of reaction as a function of foreperiod and of induced tension under varying conditions of foreperiod and load regularity during the reaction series.

irregular. When both are irregular and their combined probability small, speed of reaction is depressed and RT does vary inversely with foreperiod length. Herein may lie the explanation for Freeman's (6) finding longer foreperiods and shorter RT's with increased tension levels, whereas Davis (3) found maximum tension and shortest RT at what was apparently an optimum foreperiod interval. That is, in Davis' study, tension was always constant and minimum. The only irregularity was in the foreperiod. Although he used a large number of foreperiods, these differed in length by only hundredths of a second. Actually, they seem to fall most reasonably into five categories of foreperiod length which differed successively by .5 sec. Freeman (6), on the other hand, used four foreperiods (2, 4, 8, and 10 sec.) and two tension levels. Thus, in Davis' study only the foreperiod was variable, and its probability was about .20; whereas in Freeman's study both foreperiod and tension were variable, and their combined probability was .12. The present results suggest that the apparent contradiction of the two studies was the result of this difference in stimulus regularity rather than anything that might be attributed directly to the effects of tension level.

Other results of the present investigation are of considerable interest since they have implications both for studies of performance acquisition and performance decrement. The failure of any of the experiments to show important practice effects is not without precedent (9). Suggestive information relevant to this problem may be found in a recent study by Farber and Spence (4). Inspection of their Fig. 1 indicates that male Ss generally reached maximum reaction speed by Trial 8 of a 16-trial training series. The maximum gain in mean reaction speed appears to be about 2%. However, the same figure shows that with the exception of one of the four female groups, the reaction speed of the female Ss increased throughout the series. The maximum gain in mean

reaction speed appears to be about 25%. In view of the well-known (9) difference in RT between sexes, sex differences in RT acquisition might account for failure of the present study, and others, to find important practice effects. This hypothesis at least deserves further study and should be considered as a problem for experimental control in learning studies. Along the same line it is interesting to speculate that the sex difference in RT *acquisition* is a cultural phenomenon, men having more opportunity to engage in activities requiring fast RT's than women, whereas the sex difference in *speed* of reaction is a genetic phenomenon as evidenced by the fact that men still have shorter RT's than women even after considerable practice (4).

The results of the present study may be limited to highly massed trials. Although the main effects of the intertrial interval were not significant in Exp. I, the results of that experiment suggest that the effects of foreperiod and of load may depend on the intertrial interval used. In this regard, it is important to note that a decrement in reaction speed was observed with continued performance under the conditions of Exp. IV. Since there is no evidence of learning in any of the results, it would appear that the decrement exhibited was the result of muscular fatigue, failure to maintain attention, or a decrease in motivation. In fact, the lack of important practice effects among men suggests that the RT elicited from men may be an excellent method for studying intertrial interval and performance decrement as a primarily inhibitory and/or motivational phenomenon.

SUMMARY

Four experiments were performed with male Ss to study the effects on RT of foreperiod length, magnitude of induced muscular tension, regularity of presentation, and intertrial interval as an attempt to resolve an apparent contradiction in results between two previous studies. In Exp. I, Ss performed under constant, regularly presented foreperiod-load combinations and with one of two intertrial intervals. Experi-

ments II and III were split plots conducted with massed trials. In Exp. II, magnitude of tension was held constant for each subgroup, while foreperiods of different length were presented irregularly; in Exp. III the procedure was the reverse of Exp. II. In Exp. IV, both tension magnitude and foreperiod length were presented irregularly. The results appear to warrant the following conclusions:

1. Foreperiod length and magnitude of muscular tension are independent in their effects on RT.

2. RT varies inversely with magnitude of muscular tension except for combined foreperiod-tension irregularity of presentation of a high degree. In this case, magnitude of tension does not appear to affect RT.

3. Except for high degrees of foreperiod-tension irregularity or presentation, there is an optimum foreperiod of reaction. At least with massed practice for the present task, the optimum foreperiod is 5-6 sec.

4. When both foreperiod and tension level are presented irregularly and their combined probability of occurrence is low, RT varies inversely with length of foreperiod.

5. All of the above conclusions may depend on the intertrial interval employed.

6. At least under the conditions of the present study, repeated elicitation has no effect on RT except under the most irregularly presented stimulus conditions, in which case RT exhibits a decrement with continued elicitation.

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